



Finite Element Estimation of Meteorite Structural Properties

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Description & Outline



Chelyabinsk bolide, Photo Courtesy: The Smithsonian Institution

- Project Description
 - Goal is to develop meteor risk assessment tools
 - Entry Systems Division (TS) role: meteor entry and breakup
 - Breakup conditions are determined by meteor's structural, strength properties
- Contributions
 - Literature survey on meteor structural properties
 - Study the effect of scale on homogeneity/isotropy of meteorites
 - Nastran FEA of irregularly-shaped meteor
 - Develop ideas for PhD research

Literature Survey



- Chondrite meteorites have three components
 - Chondrules: round stones, silicates, 1-2mm wide
 - Inclusions: feldspar, metal refractories, similar size
 - Matrix: sub-micron particles, low strength
- Meteorite bulk properties can be estimated from constituent properties and composition



LL Ordinary Chondrite, NAU,
<http://nau.edu/cefns/labs/meteorite/classification/ll-ordinary-chondrites/>

Property	Kamacite	Taenite	Forsterite	Fayalite	Pyroxene	Quartz	Concrete	Units
Density	7.90	7.8-8.22	3.275	4.392	3.0-4.0	2.20	3.1-5.8	g/cc
Young's Modulus	186-206	130-198	195	134	120-190	72	25	GPa
Poisson's Ratio	0.24-0.42	0.37-0.44	0.25	0.33	0.21-0.30	0.17	0.25	
Shear Modulus	70-78	56-72	78	52	47-78	31	10	GPa
Compressive Yield Strength	306-380	760	323					MPa
Compressive Strength	398-520	840	437		81-480	1100	17-36	MPa
Tensile Yield Strength	300-400	200-600						MPa
Tensile Strength	43	500-1100	62		11-26	48	2.5-7.0	MPa

*Data are valid at sea-level temperature and pressure.

Need test data to fill in the blanks, especially at entry-relevant conditions

Effect of Scale on Homogeneity



- Constituents have significantly different material properties
 - Density can vary from 2 to 8 g/cc
 - Young's modulus varies from 100 to 200 GPa
 - Matrix material is very weak, sub-micron particles
- Study sensitivity of chondrite properties to varied constituent properties
 - Unit cell computer experiments
 - Cracks and voids neglected in analysis



LL Ordinary Chondrite, Photo Courtesy: NAU, <http://nau.edu/cefns/labs/meteorite/classification/ll-ordinary-chondrites/>



Cracked meteorite, Photo Courtesy: Derek Sears and Katie Bryson

Effect of Scale on Homogeneity



Upper half of a stress cube, simulated in MSC Nastran. Plotted is the zz-strain due to a uniform pressure applied normal to the z-surface. Nodes on the plane of symmetry are free to move in the xy-plane, restricted in rotation and z-motion.

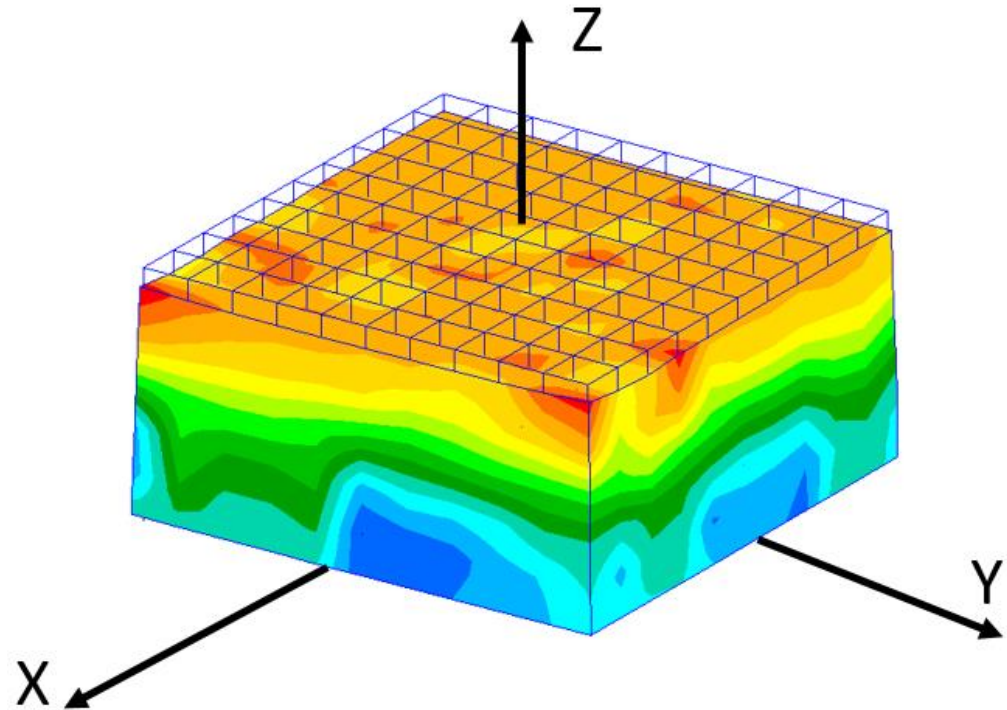
Stress cube is 75% chondrules, 15% metal, 5% feldspar, and 5% matrix by volume.

The average strain tensor, ε , provides the Young's modulus and Poisson's ratios of the cube.

$$E_z = \sigma_{zz} / \varepsilon_{zz}$$

$$\nu_{zy} = \varepsilon_{yy} / \varepsilon_{zz}$$

$$\nu_{zx} = \varepsilon_{xx} / \varepsilon_{zz}$$

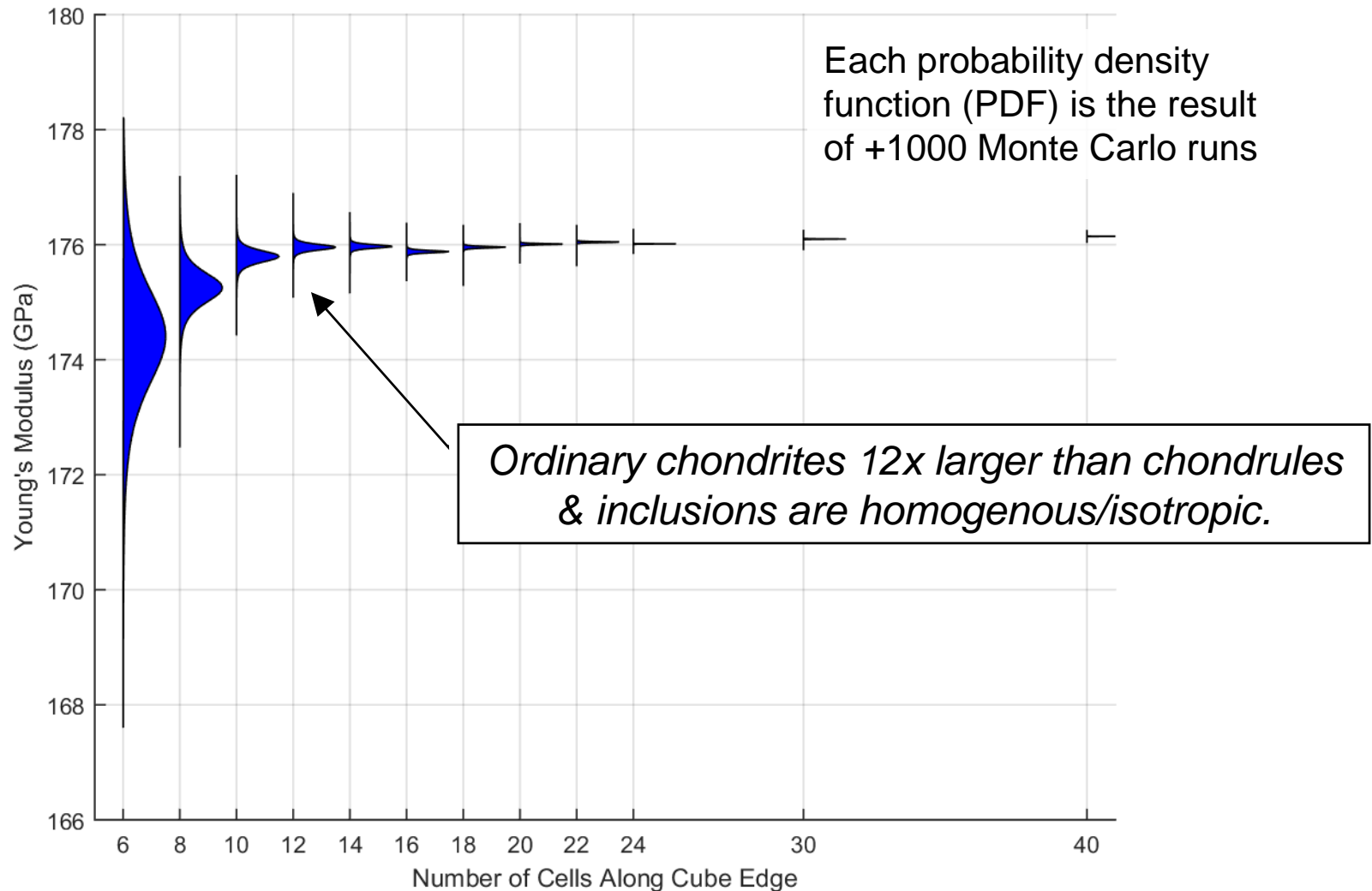


Material	E (GPa)	ν (-)	% Vol.
Chondrule	190	0.23	75%
Metal	208	0.27	15%
Feldspar	103	0.3	5%
"Matrix"	0.001	0.49	5%

Effect of Scale on Homogeneity



Distribution of Young's Modulus with Random Arrangement of Constituents



As the relative size of the cells decreases compared to the size of the stress cube, the arrangement of the constituents within the cube becomes less significant. This is illustrated by the decrease in variance with increase in number of cells.

Irregularly-Shaped Meteorite FEA

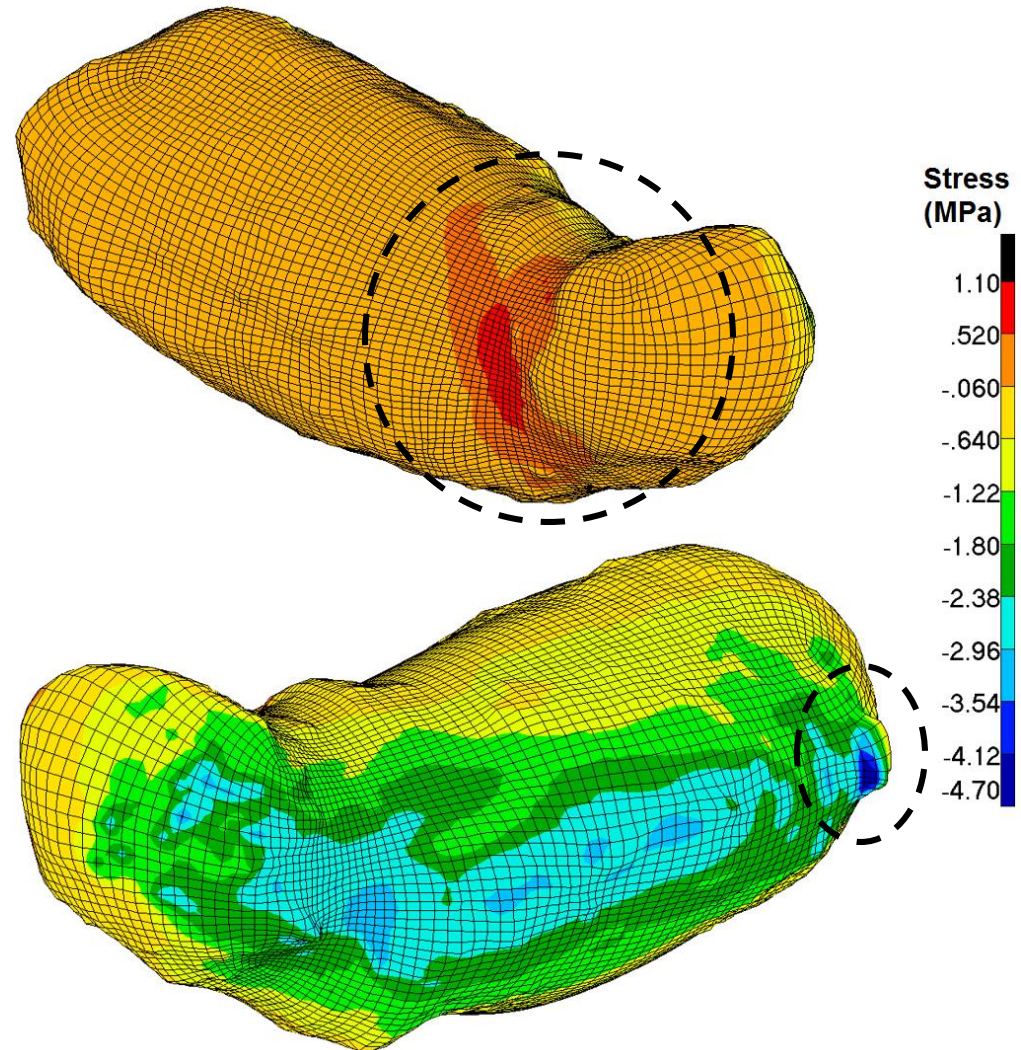


Meteor assumed isotropic/homogenous

Static stress distribution in a meteor with the geometry of Itokawa at the size of Chelyabinsk (~20m), estimated using MSC Nastran. The loading is a surface pressure distribution from CFD. Stagnation pressure is 30 atm (~3 MPa) at a velocity of 20 km/s.

Top The leeward half of the meteor, colored by maximum principle stress. Tensile failure will likely occur at the “neck” of the meteorite.

Bottom The windward half of the meteor, colored by minimum principle stress. In compression, prominent surface features will likely fail first.



- How strong can a meteoroid be?
 - Goal: develop a methodology to generate PDFs of the strength of stony meteoroids, given unknowns about cracks, voids, etc.
 - Meteoroid strength and uncertainty are needed in a PRA environment
 - Ancillary contribution: benefits hypothetical “disruption” mission design
 - Modeled from historical data, computer simulations
 - Simulation specs TBD - FEM vs DEM, fabric tensor, peridynamics
 - Validated against destructive testing, ballistic firing of meteorite samples or analog materials, e.g. basalts & concrete
 - PDF based on 3 levels of information, categories
 - Unresolved body (most likely)
 - Resolved body - spectra & radar measurements (somewhat likely)
 - Probed/visited body - nearly everything known (unlikely)
 - Potential Contributions
 - Validated meteorite structural analysis tool
 - Sensitivity analysis on factors affecting meteoroid strength
 - Probabilistic prediction of metrics from historical data and simulation

Summary



- Ames is applying EDL know-how to meteor entry
- Breakup event is largely dependent on exo-atmospheric structure, composition of meteoroid
- Some material properties found in the literature
- Effect of scale on homogeneity determined through FEA
- Stresses on irregular geometries estimated with Nastran
- Interest in continuing meteoroid research for PhD at GT

Acknowledgments

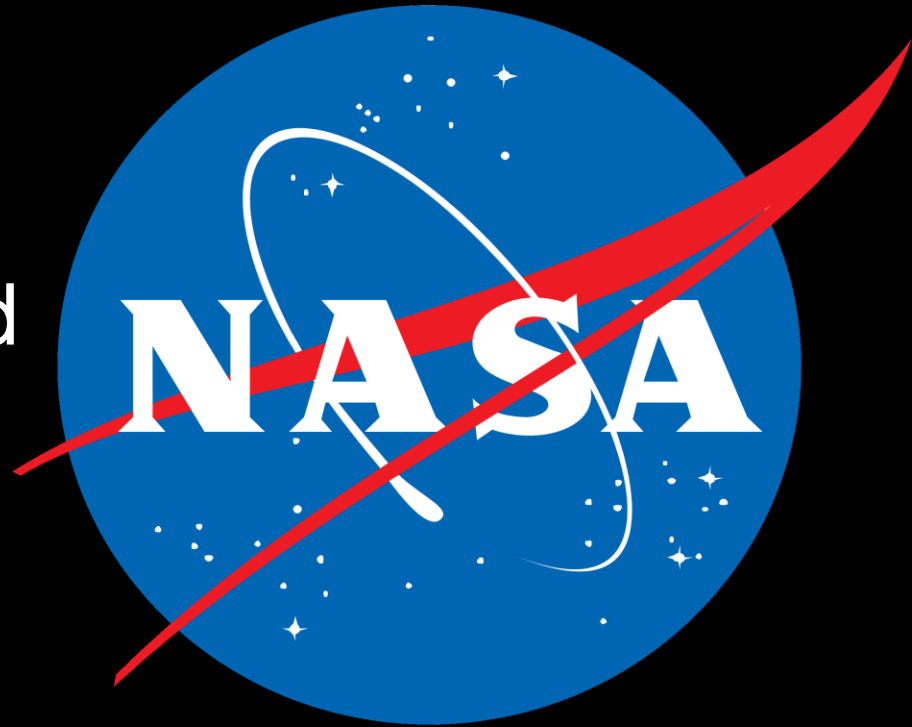


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Questions?

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Effect of Scale on Homogeneity

